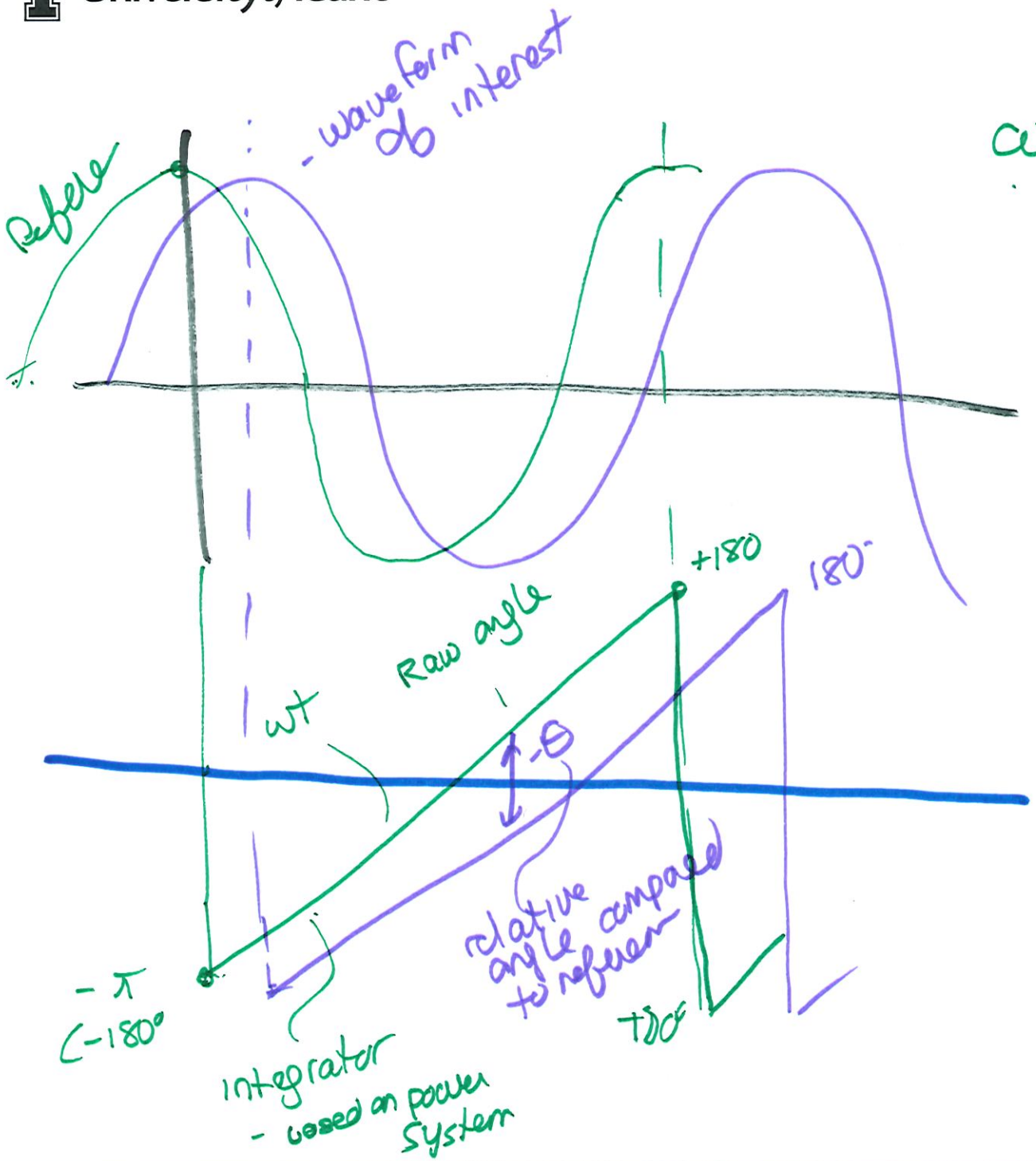
University of Idaho

ECE 444 / ECE 544 / CS 444 / CS 544 Supervisory Control and Critical Infrastructure Systems

Session 23



$\cos(\omega t + \theta)$

relative angle
- actually a function of time

SCADA
- meters measure
|V|, |I|
P, Q (pf)
⇓
communicated to control center

System State Estimation

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- Current practice
  - » SCADA – scans on the order of 1-5 seconds
    - – Somewhat variable rate
    - – |V|, P, Q,
    - – No angles
  - » To get angles and missing measurements need a non-linear state estimator
    - – Iterative solver
    - – Based on a model of the power system

steady-state & quasisteady state equations/ behavior

– add circuit breaker status ⇒ system topology

– solves a system of equations based on power system model – nodal circuit equation

→ P, Q equations at every node & branch

– more eq. than unknowns

– measurement error

↓

|V|, θ at every node/bus

Hybrid System State Estimation with Added PMU Data

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- The conventional SCADA isn't going away
  - » Infrastructure is in place
  - » Implementation of PMUs is limited in many utilities
- Supplement the state estimation with PMU data where |V| and angle are measured directly
  - » Still more of a future implementation
- Variant on this is using PMU data resolve anomalies in the conventional state estimator results (done now)

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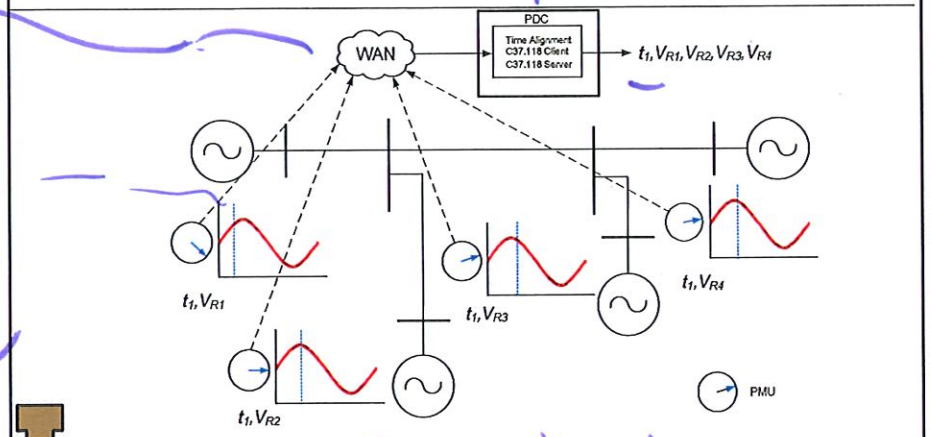
Phasors With Common Timestamp Provide a "Snapshot" of the System

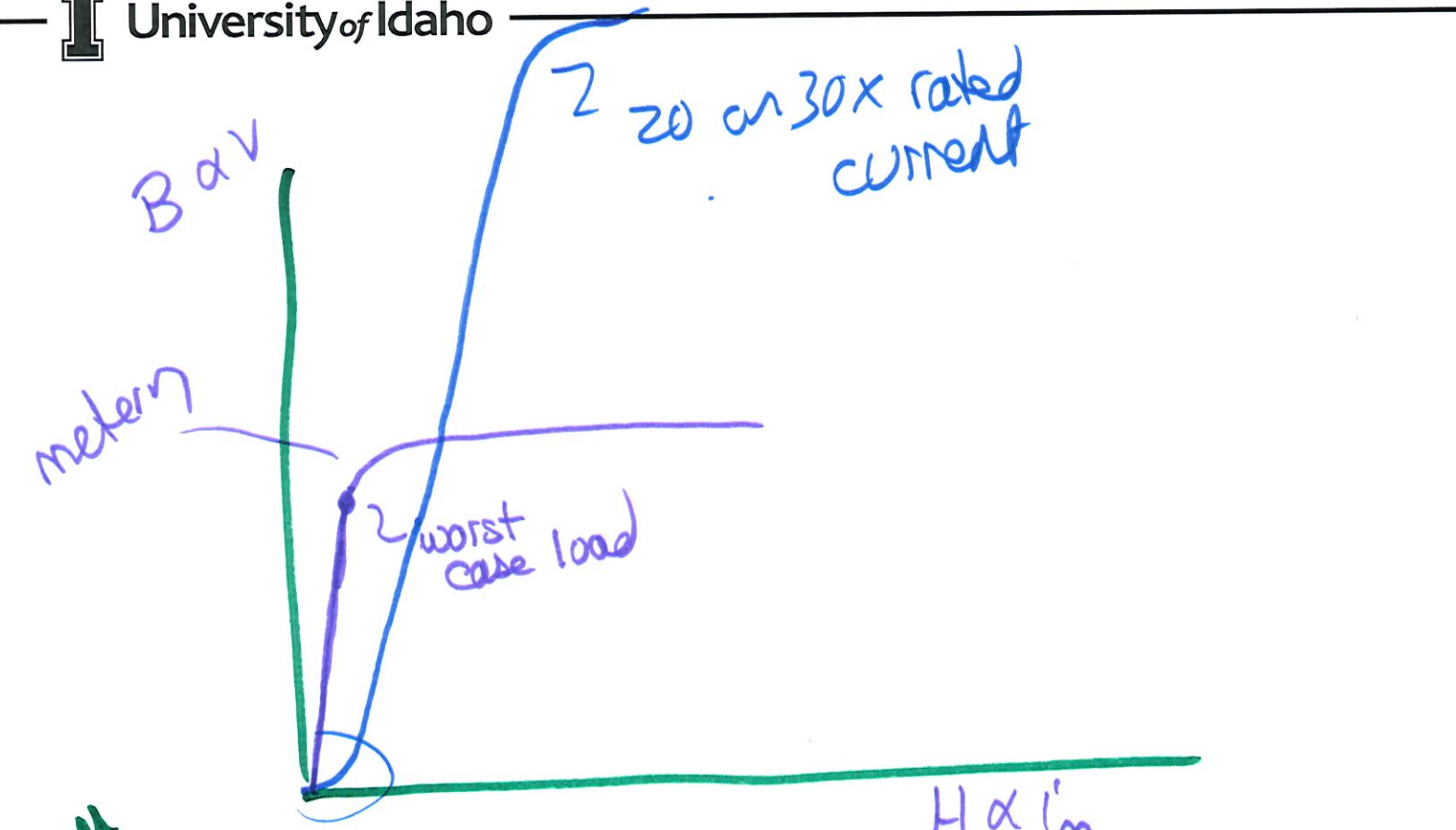


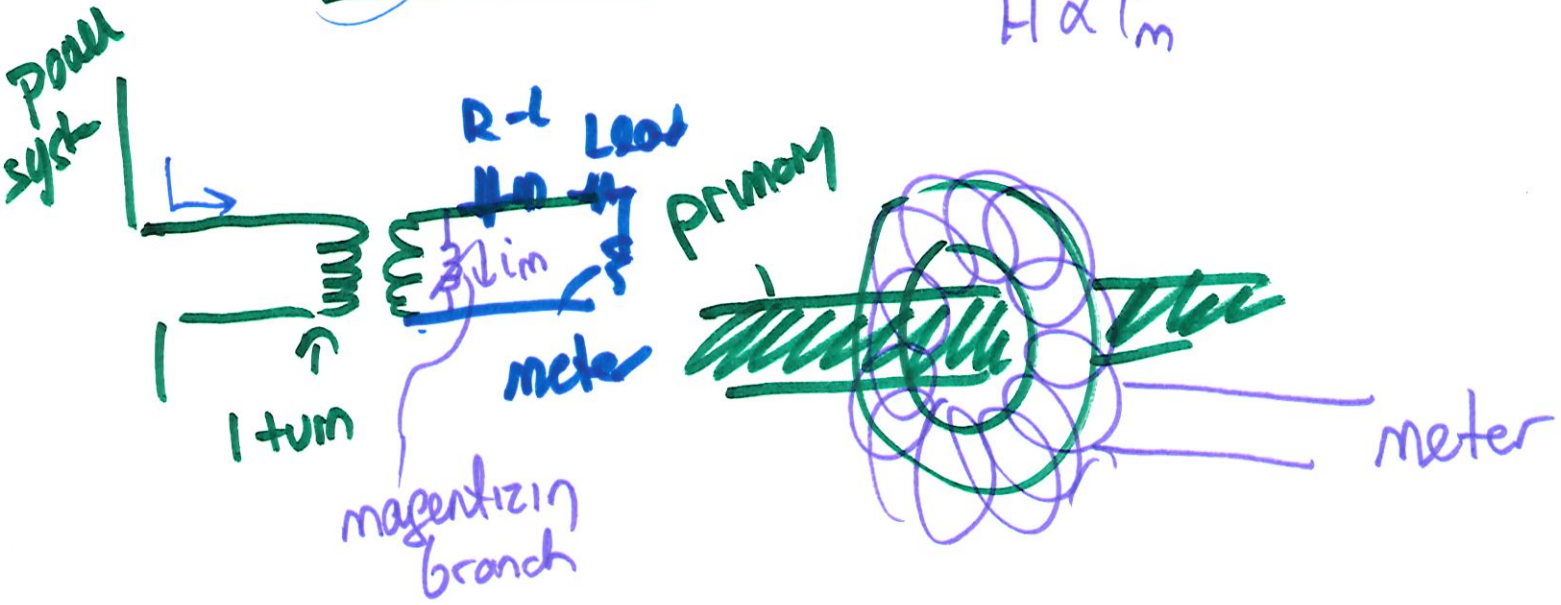
measurements have time stamp

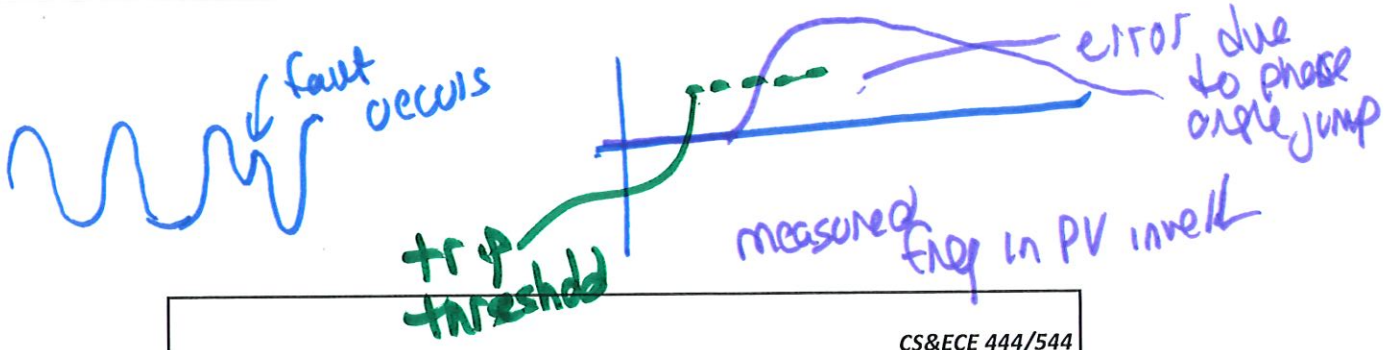
System Needs

- Precise time clocks in substations
- phasor measurement unit (PMU)
  - sample V, I → 16 - 64 or high samples per cycle
  - compute phasor
    - → older used Fourier filter (cos, sine)
    - Newer ~~Quarter~~ Quadrature modulate filters (IEEE standard related to synchrophasors)
  - add time stamp

- comms network
- Data concentrators


B ∝ V
meter
2 20 or 30 x rated current
2 worst case load
H ∝ i'm


Power syst
R-L Load
primary
1 turn
magentizing branch
meter
meter



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Tolerances

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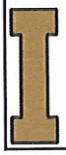
- Total Vector Error (TVE) - Limit – (≤ 1%)
- Frequency Error (FE) - Limit – (≤ 0.005Hz)
- Rate of Change Frequency error (ROCOF) - Limit (≤ 0.01 Hz/s)

↳ faster message transfer

- P-Class (Protection—fast response)
- M-Class (High precision monitoring, slower needs) ← metering class



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Data Transmission

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- standard data format
- IEEE C37.118 family of standards (dual label with IEC)
- Frame rates (data updates)
  10 messages/sec
  1 2
  1 s. 20, 30, 60, 120

- Defines data frame → 3phase V, I, P, Q, f
- minimum communicat. network channel capacity ROCOF

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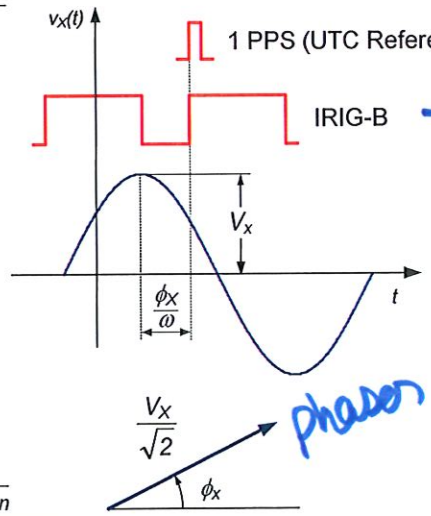
Precision Time Protocol (PTP)

- IEEE Std 1588
- ordinary clock - time source
  - single PTP port in a clock domain
  - introces min time delay
- Boundary clocks - if have multiple PTP ports
  - maintain timescale within domain
  - propagate this clock signal
    - provide info on transit
    - propagat- delay

Phasor Representation With Respect to the 1 PPS UTC Reference



→ also standard for distributing time over ethernet

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Synchronized Phasor Measurements

- Communication Protocol
  - » IEEE C37.118
  - » Vendor specific (mostly legacy equipment)
- Separate communication network from SCADA

Four Message Types

Main use

- Data messages:
  - » Measurements made by the phasor measurement unit.
- Configuration:
  - » Machine-readable message describing the data types, calibration factors, and other meta-data that the phasor measurement unit or phasor data concentrator sends.
- Header information:
  - » Human readable descriptive information sent from a phasor measurement unit or phasor data concentrator provided to the user.
- Commands: - out to PDC → to actuators
  - » Codes sent to the phasor measurement units or phasor data concentrators for control or configuration.

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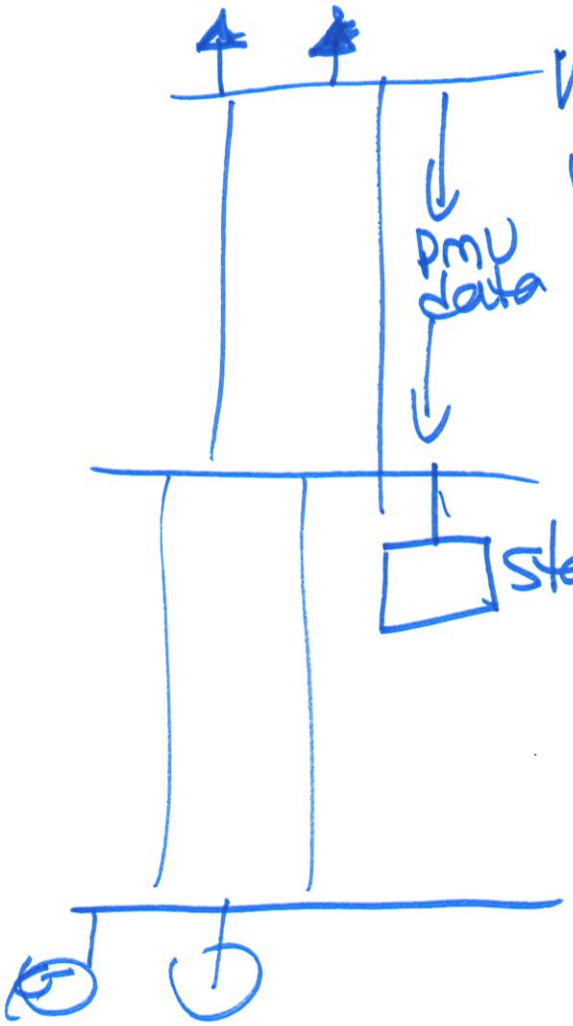

Voltage at bus fluctuates - not meeting acceptable levels

Static Var Compensator (SVC)
- dynamic reactive compensator
- regulate voltage at remote bus

Algorithm to Detect Unstable Power Oscillations and Take Remedial Action

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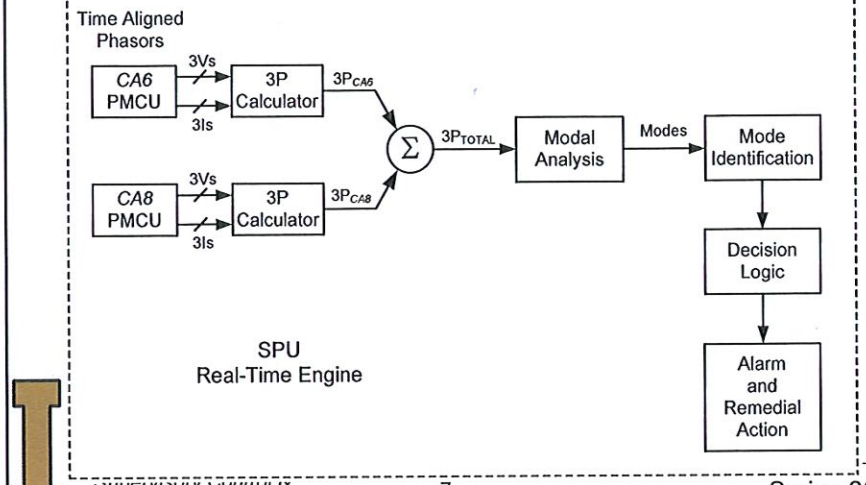

Remedial action scheme (RAS) of special protection scheme (SPS)

Complex Multi-Task System Integrity Protection Scheme

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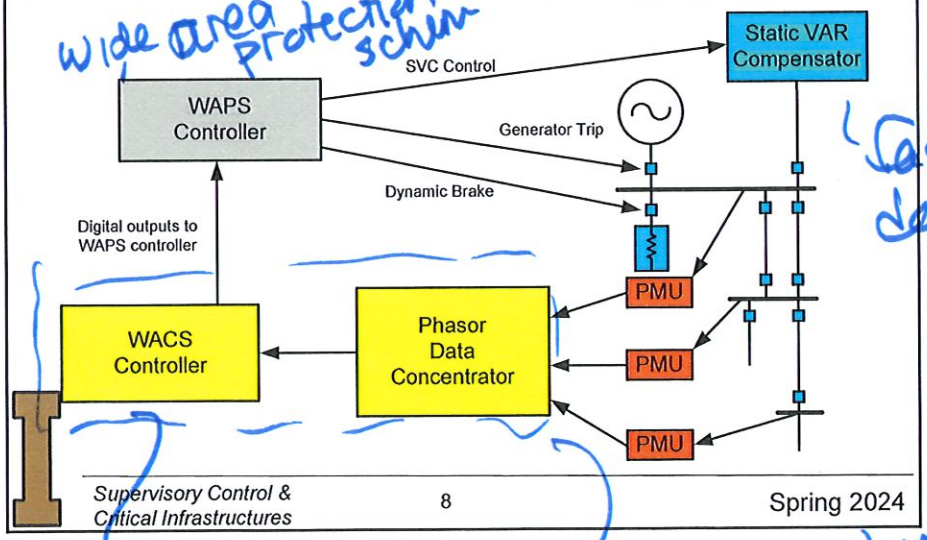

task damping

Wide area control system

combined into one box

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Format of Data Frame

- One frame is one set phasors at a time instance V_{abc}, I_{abc}, P, Q, f, df/dt
  - » Positive sequence components
- IEEE C37.118 standards define the frame organization

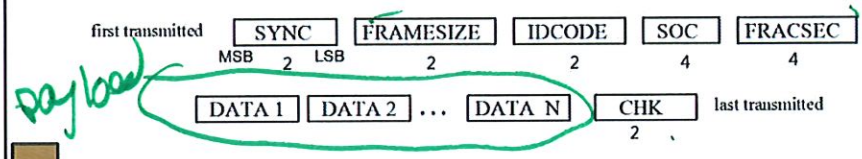

Figure 3—Example of frame transmission order

Data Frame Organization

No.	Field	Size (bytes)
1	SYNC	2
2	FRAMESIZE	2
3	IDCODE	2
4	SOC	4
5	FRASEC	4
6	STAT	2
7	PHASORS	4xPHNMR or 8xPHNMR
8	FREQ	2/4
9	DFREQ	2/4
10	ANALOG	2xANNMR or 4xNNMR
11	DIGITAL	2xDGNMR
	Repeat 6 to 11	
12+	CHK	2

Configuration Frame: Three Options

- **CFG-1: All of the data a PMU/PDC can report**
- CFG-2: Indicates measurements only
- CFG-3: Extends CF-1 and 2 that define PMU characteristics and quantities sent

upstream PDC or control center

or controller

Header Frame

No	Field	Size (bytes)
1	SYNC	2
2	FRAMESIZE	2
3	IDCODE	2
4	SOC	4
5	FRACSEC	4
6	DATA 1	1
K+6	DATA K	1
K+7	CHK	2

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Command Frame

No	Field	Size (bytes)
1	SYNC	2
2	FRAMESIZE	2
3	IDCODE	2
4	SOC	4
5	FRACSEC	4
6	CMD	2
7	EXTFRAME	0-65518
8	CHK	2

Command Functions Include

- Turn off transmission
- Turn-on transmission
- Send header
- Send CFG-1 frame
- Send CFG-2 frame,
- Send CFG-3 frame

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